TAKE PICTURES. FURTHER.

TDM Metrology Development

“You want me to measure WHAT?!?”

Cormic K. Merle

August 17, 2004

TAKE PICTURES. FURTHER.

Acknowledgements

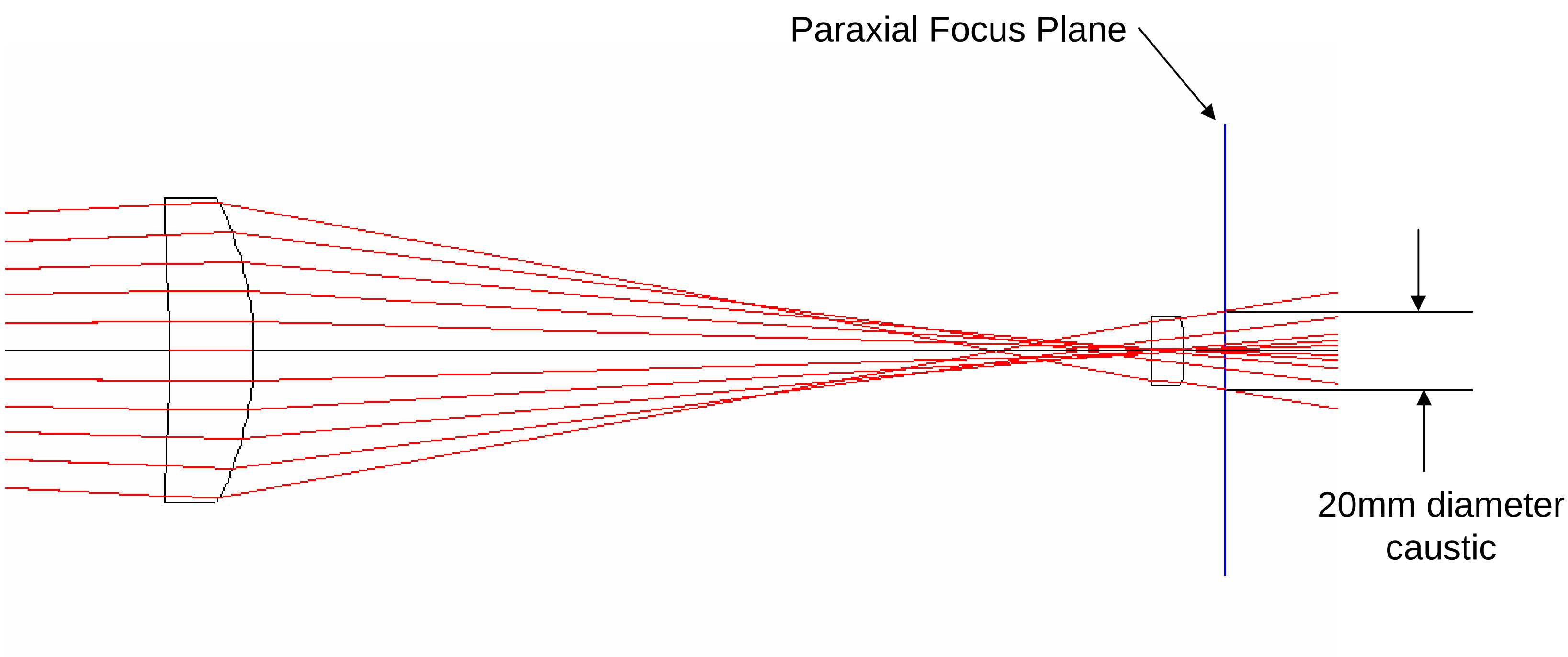
I would like to thank David Fischer of ITT and Jim Burge of the University of Arizona for their valuable input and technical expertise.

TAKE PICTURES. FURTHER.

TDM Requirements

Vertex Radius	7596 mm
Conic Constant	-1.000
Part Diameter	1.87 m (full part)
Off Axis distance (vertex to part center)	1321.524 mm (f/0.85 parent)
Radius of Curvature Tolerance	+/- 2 mm
Knowledge of ROC	50 μm *****
Off Axis Distance Tolerance	+/- 2mm
Knowledge of Off Axis Distance	100μm *****
Tolerance on Conic	+/- 0.0001
Knowledge of Conic	+/- 0.00001 *****
Test set uncertainty (surface error) (Flowdown from top-level requirements)	6.45nm rms LSF ***** 3.50nm rms MSF *****

Typical Offner Null Design



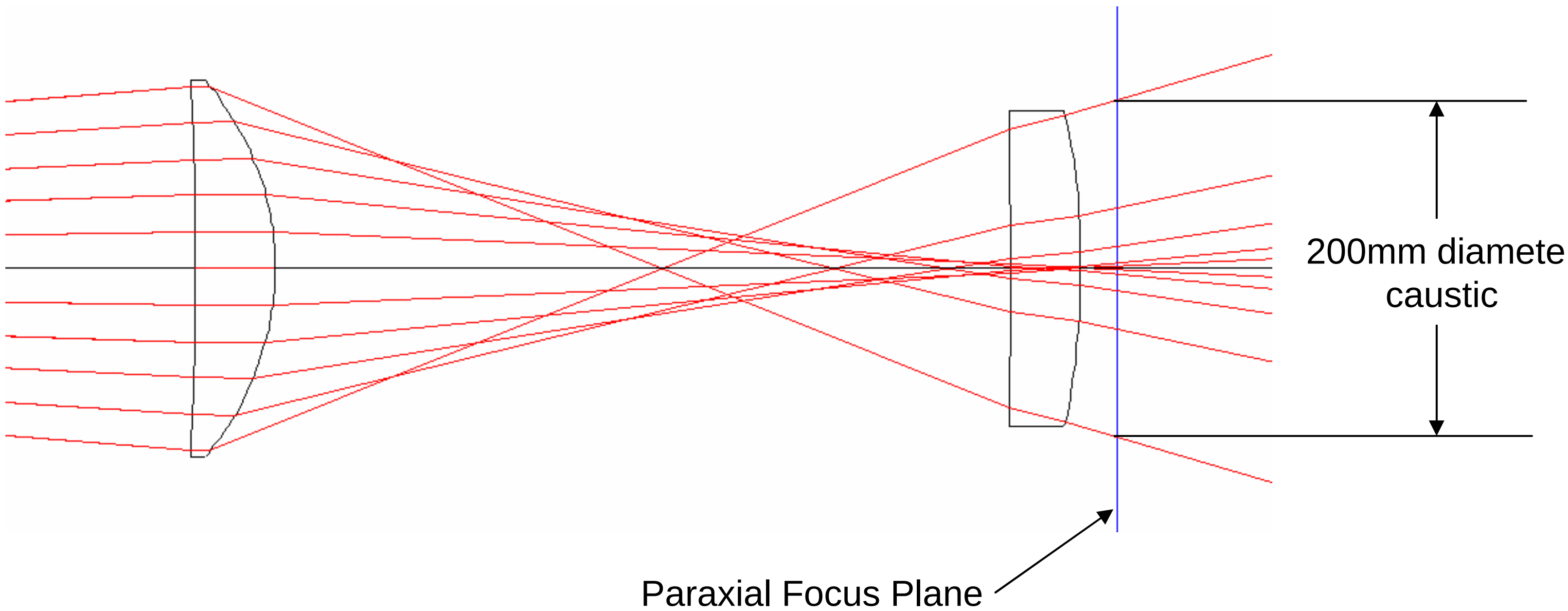
Wavefront fit ~0.003λ rms (~2nm)

f/1.5 parent mirror

Not So Typical

TAKE PICTURES. FURTHER.

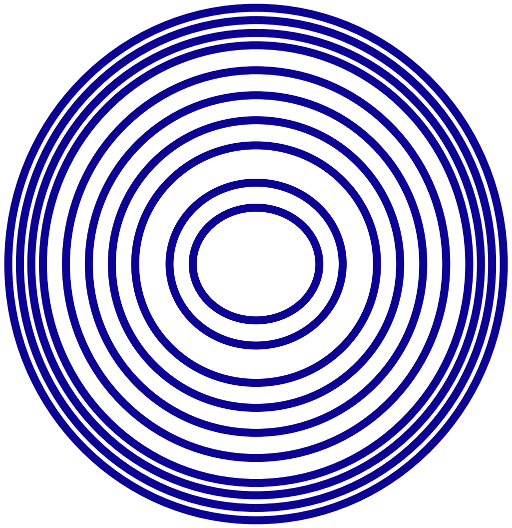
Vertex Radius	**7596 mm**
Conic Constant	**-1.000**
Part Diameter	**1.87 m (full part)**
Off Axis distance (vertex to part center)	**1321.524 mm (f/0.85 parent)**



Wavefront fit ~0.030λ rms (~19nm)

Now What?

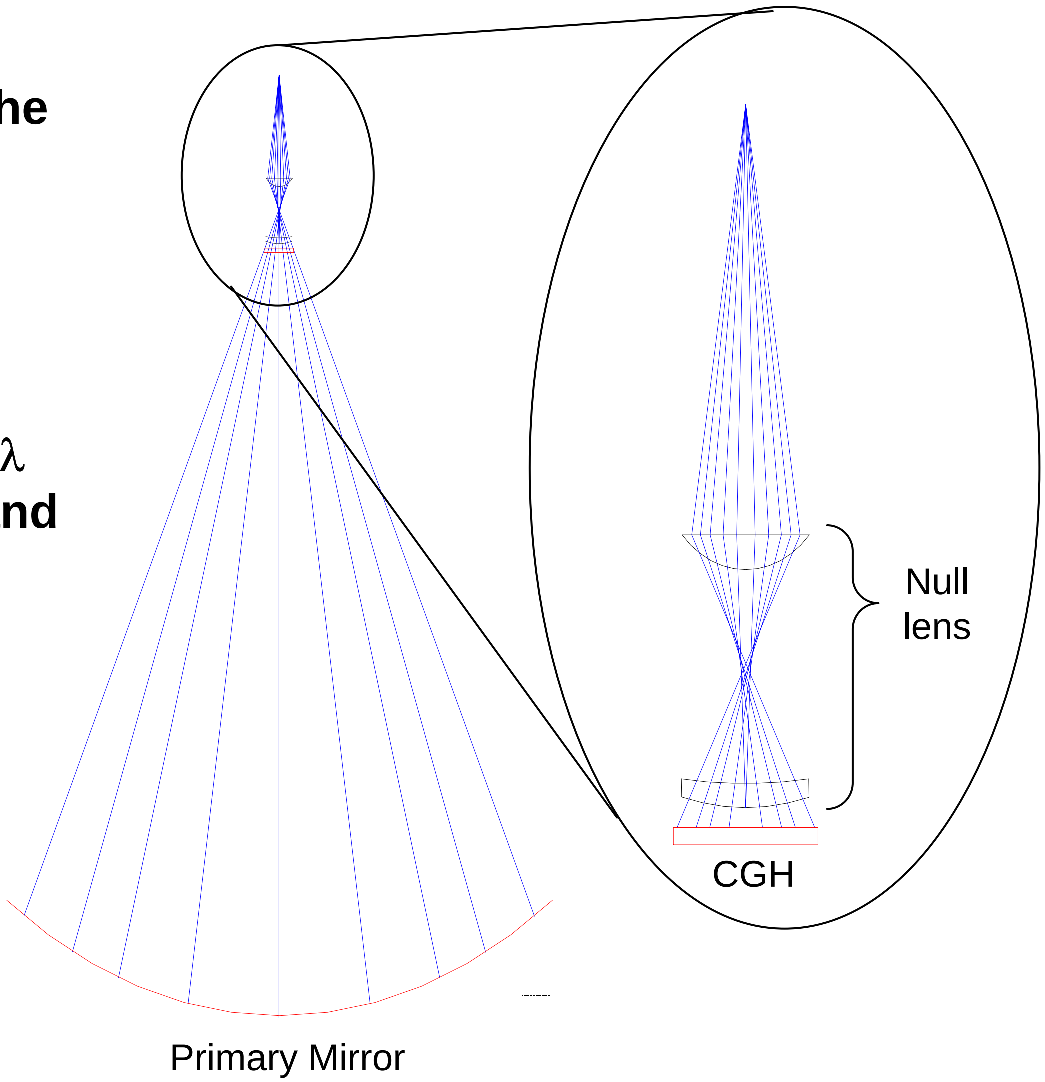
- **Significant residual wavefront error in the design**
  - Need to back out from measurements with low uncertainty
  - Manufacturing tolerances are inadequate to achieve required wavefront knowledge
- **3 element null could reduce wavefront error in design**
  - Analysis shows this is even less stable
- **Now What?**
  - **Computer Generated Holograms** to the rescue!



TAKE PICTURES. FURTHER.

Use of CGH to calibrate the null lens

- Use a computer generated hologram CGH to measure the null lens
- The CGH uses diffraction to reflect light, simulating a perfect primary mirror.
- CGH errors are only ~ 0.015 λ rms, and can be measured and removed from the data



TAKE PICTURES. FURTHER.

Rationale behind CGH

- **Null corrector can provide good reference with ??? nm rms surface**
- **Errors from the null lens will be smooth, low frequency. Due to misalignment, refractive index variations, figure errors in the spherical lens surfaces**
- **CGH uses axisymmetry for test of parent. CGH consists of a pattern of concentric rings written in chrome onto a flat glass substrate**
- **CGH has excellent accuracy, limited by**
  - **Fabrication errors** – laser writer uses interferometric feedback for control
  - **Surface flatness** – well polished, careful support, easy to qualify
  - **Wavelength of light** - stability of HeNe source, control of temperature

TAKE PICTURES. FURTHER.

Limitations for CGH test

- **State of the art CGHs give accuracy to ~0.015λ rms for f/1 tests. Almost there. To get better accuracy, we need to measure errors from CGH and remove them from the data.**
- **Sources of error for CGH:**
  - Substrate flatness:
    - make good flat, qualify with direct measurement
    - Rotate CGH to average out HF errors in surface
  - Distortion of CGH pattern
    - Use accurate laser writer
    - Average out azimuthal errors by rotating CGH
    - Measure non-axisymmetric errors directly, correct for them

CGH fabrication errors from circular laser writer

TAKE PICTURES. FURTHER.

Wavefront errors at position (r, θ) depend on:

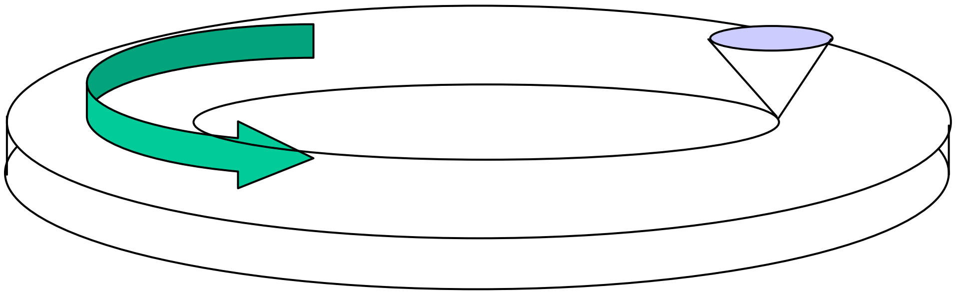
- **Δr: ring position error**
- ***S*: CGH line spacing at order *m***

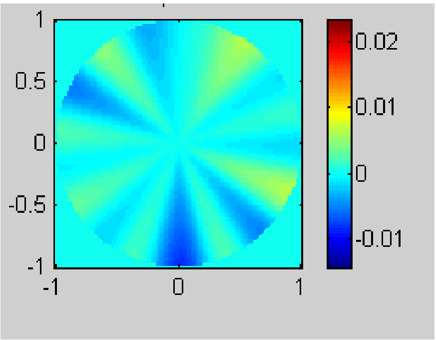
$$\Delta W(r,\theta) = -m\lambda \frac{\Delta r(r,\theta)}{S(r)}$$

Substrate is rotated using air bearing spindle

Spindle wobble causes spoke-like errors

This error is readily overcome



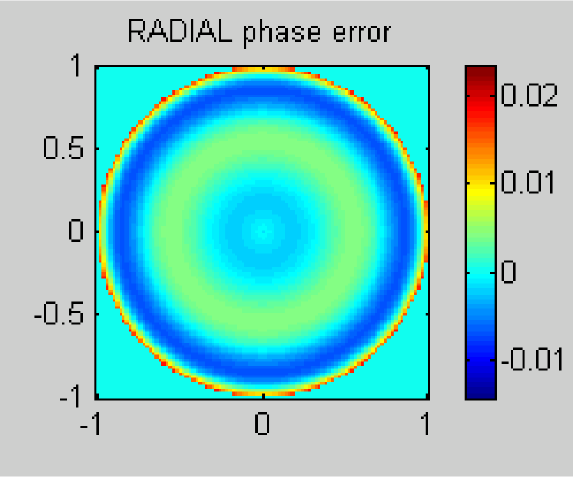


Radial position controlled using air bearing, measured with interferometer

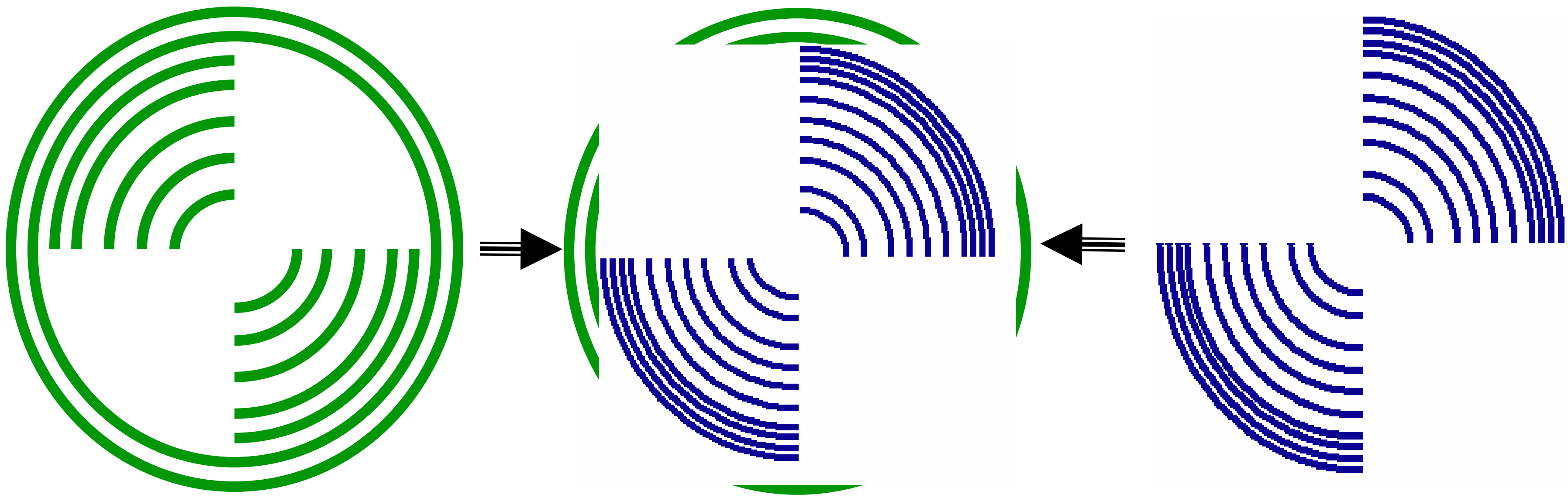
Errors in radial coordinate causes ring-like errors

Accuracy is ~0.05 µm rms$\Rightarrow$ ~10 nm rms surface

Propose solution using Dual CGH



The Dual CGH

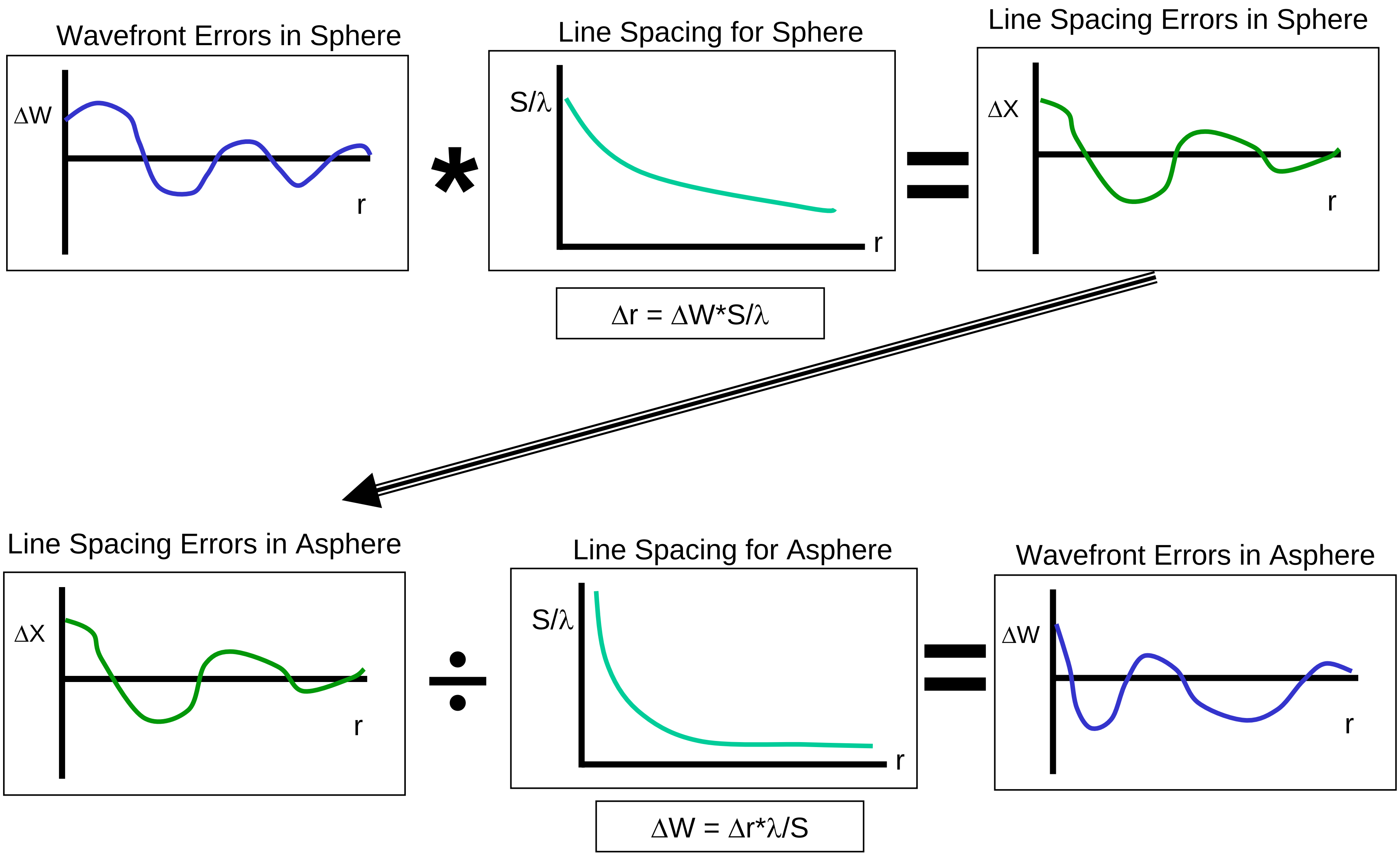


Spherical Prescription | Segmented Hologram | Aspheric Prescription

- **Segment the CGH into quadrants, so the spherical and aspheric prescriptions to be measured separately (ref Reichelt 2002).**
- **Both patterns are written at the same time, so any radial coordinate error will cause the same error for both patterns**

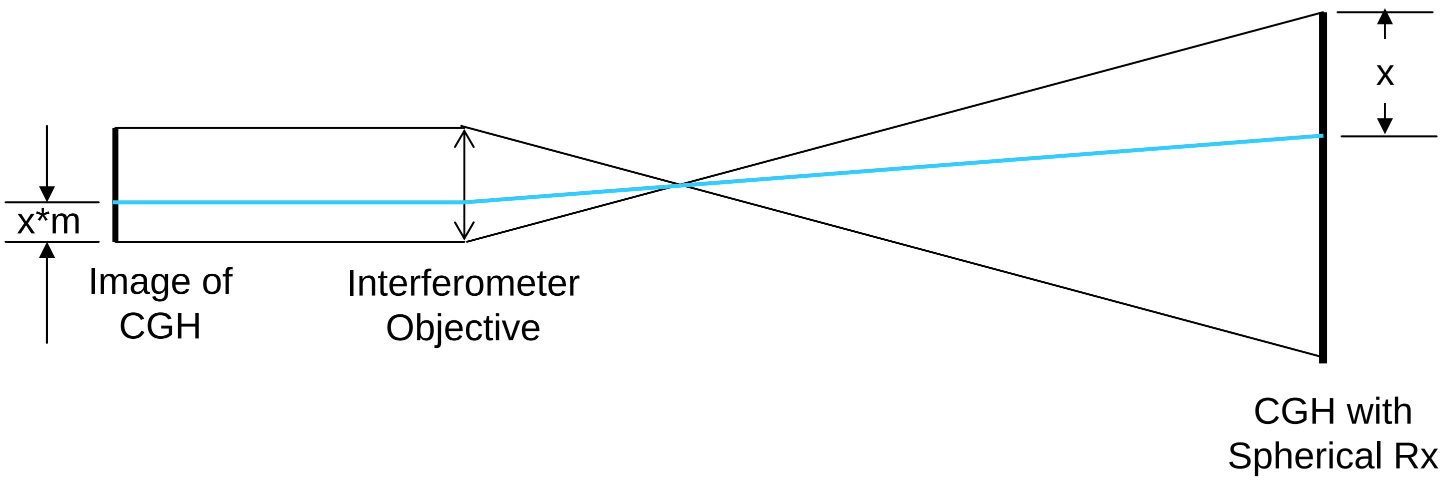
Transfer Knowledge from Sphere to Asphere

TAKE PICTURES. FURTHER.



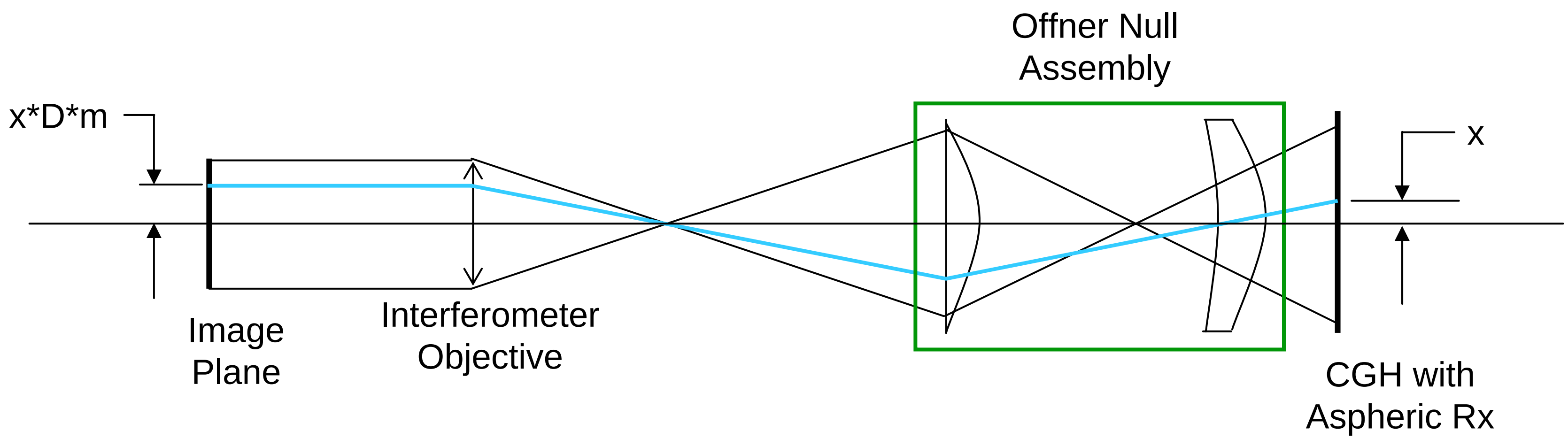
TAKE PICTURES. FURTHER.

Taking Distortion Into Account



An interferometer images a CGH with a spherical prescription with no distortion

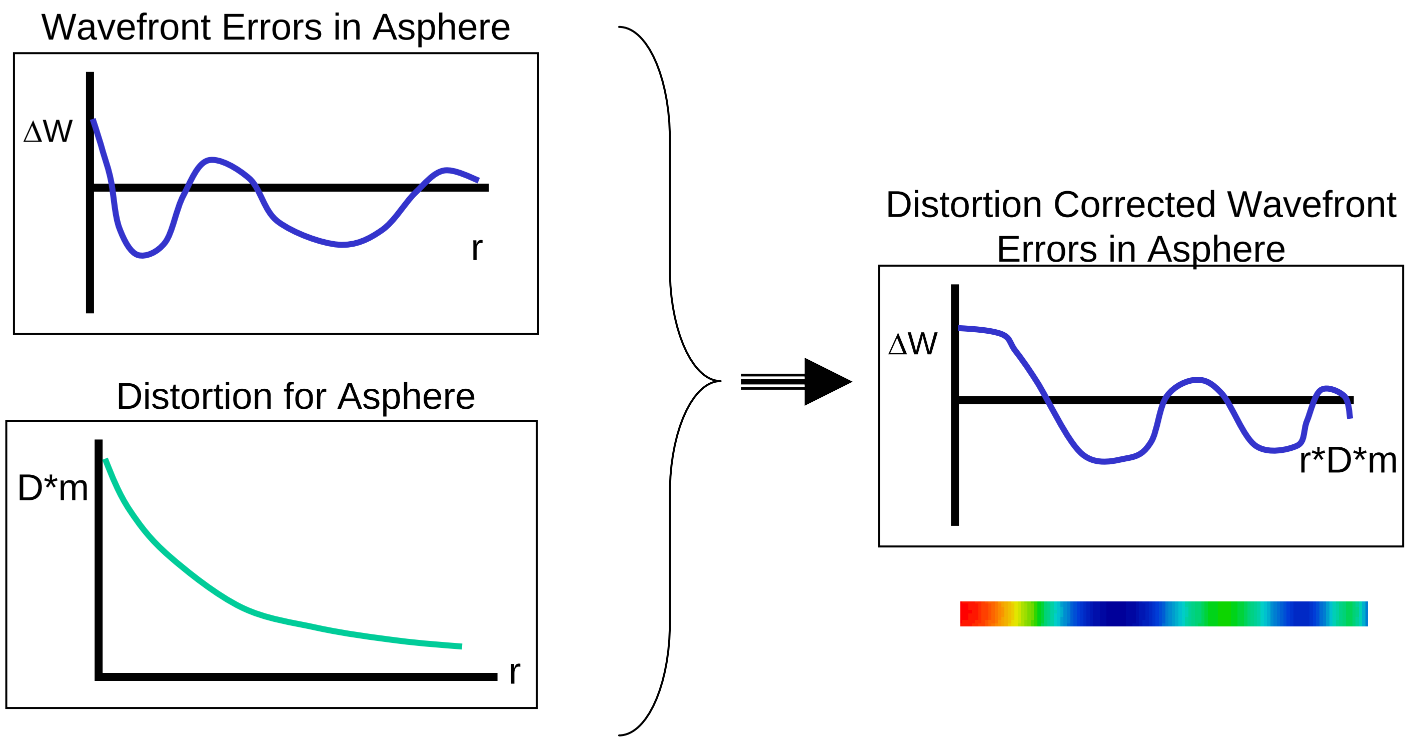
Taking Distortion into Account



D is the distortion mapping function that is dependant on ray position on the CGH

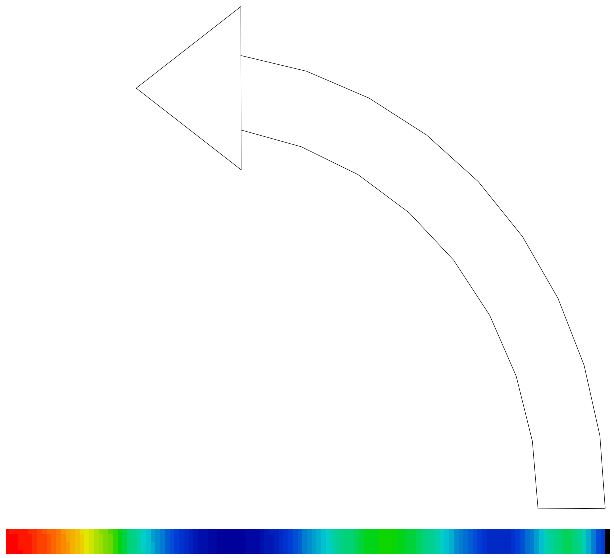
- **Large spherical aberration imparted by the Offner Null distorts mapping function of CGH with aspheric prescription**

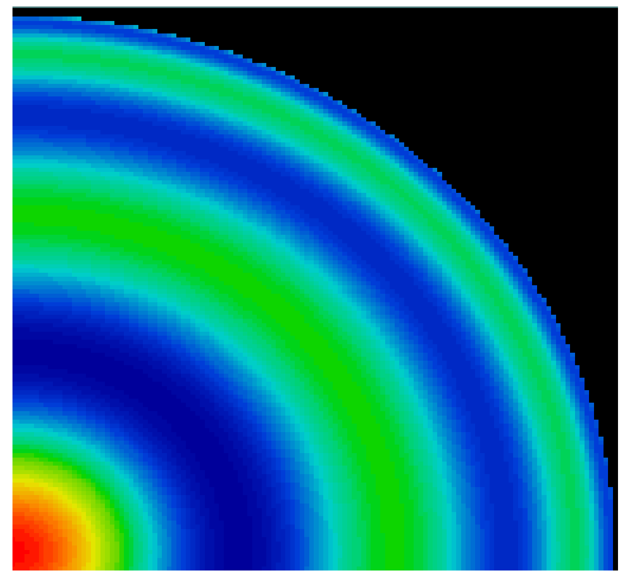
Correcting Distortion



- **Distortion Correction does not effect amplitude of ΔW**
- **Distortion Correction only effects waveform mapping**

Create Useful 2 Dimensional Data





- **Sweep data to make 2 dimensional back out data**

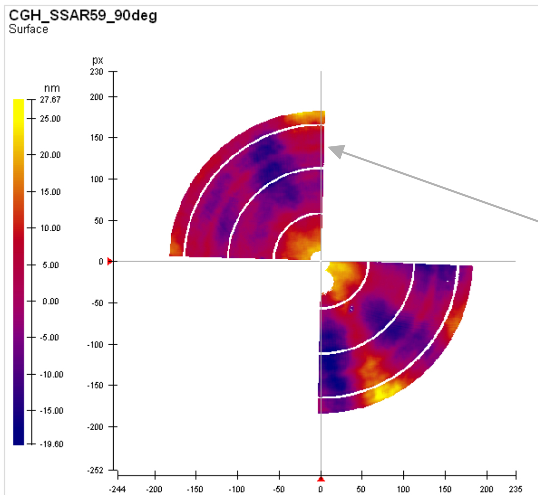
Technology development plan

1. Demonstrate concept using quadrant CGHs with spherical surfaces.
2. Demonstrate ability to back errors out of a CGH null lens test using a smaller, existing, well known null corrector
3. Fabricate full scale prototype to test software, control of laser writing machine

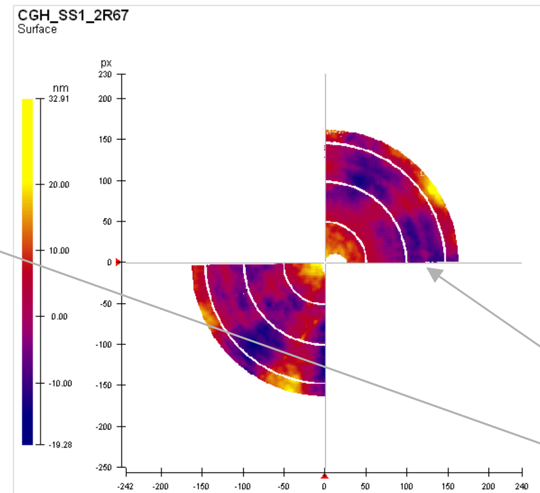
TAKE PICTURES. FURTHER.

Preliminary results

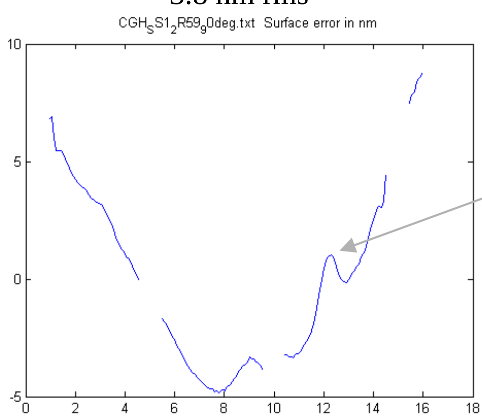
Sphere 1 R = 59mm
8.1 nm rms



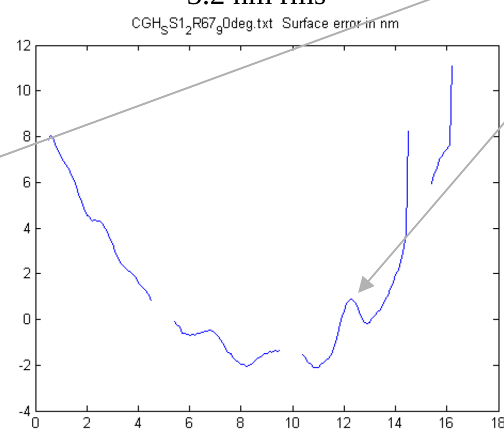
Sphere 2 R = 67 mm
7.0 nm rms



Radial portion of Sphere 1
3.8 nm rms



Radial portion of Sphere 2
3.2 nm rms



Notice the 2 nm zone at r=12.3 mm

In both patterns!

Preliminary results

TAKE PICTURES. FURTHER.

Calculation of CGH error for separate quadrants

CGH errors here match to ~0.01 µm rms
Wavefront effects will match to < 2 nm rms!